DEVELOPING INFORMAL REASONING SKILLS IN ILL-STRUCTURED ENVIRONMENTS. A CASE STUDY INTO PROBLEM-SOLVING STRATEGIES

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Abstract

The issue of teaching broad-based thinking processes, rather than more content-specific skills, continues with the emphasis on the development of cognitive skills through the use of investigation, reflection and analysis, synthesis and evaluation to generate or refine knowledge. Such skills are more widely associated with the more complex ('higher order') learning strategies proposed by Bloom (1956) where thinking takes place in the upper levels of the cognitive processing hierarchy. It has been suggested by Jonassen (2000) that the development of these 'higher order' cognitive skills can be achieved through problem solving in environments that present tasks in ill-structured domains. Researchers experimenting with computer-based learning environments are attempting to scaffold learners during a cognitive task that is usually presented in the form of a problem. The scaffolding is provided in the form of a cognitive tool (Jonassen, 1996) that provides both cognitive and computational support to guide and assist the learner in defining the issues and developing strategies for problem solving and learning. This paper reports on a study that further examined the strategies used by learners in developing responses to ill-structured (Jonassen, 2000) or open-ended problems (Land & Hannafin, 1996). Based on this data it should be possible to develop specific cognitive tool(s) (Jonassen, 1996) that assist learners with problem identification, evaluation of evidence and the construction of a solution.

Keywords

Ill-structured problems, reasoning, scaffolds, cognitive tools ,learning environments, problem-solving

Introduction

Constructivist learning theory shifts the focus for organising knowledge construction from the teacher to the learner. Learners therefore need to develop a range of information processing skills to cope with this change. When faced with the responsibility for knowledge construction, they are thrown on their own management resources. While some may have the metacognitive skills to cope, many fend poorly in the increased complexity of such a learning environment. Many see the task as daunting and complex and feel ill-prepared for such creative freedom and choice of direction. Such learners need tools to support them to represent the knowledge they are acquiring and to facilitate higher-order thinking.

The research has focused on the three main areas: *problem clarification* (identifying the nature of the task and what information was required or provided); *solution formulation* including data collection and the solution process (sorting out the resources and generating new information as required); and *presentation of argument* for the solution (identifying propositions and the appropriate evidence for support or refuting the argument).

This study was based on the theoretical assumption that the most effective use of computer technology in an educational setting is when learners use it as a cognitive tool (Jonassen, 1996). However, to be used effectively as a cognitive tool, they must apply problem solving processes and employ higher-order reasoning strategies leading to cognitive growth. As such, the technology becomes a ‘mind-extension cognitive tool’ (Derry & Lajoie, 1993, p.5). Many cognitive tools facilitate metacognitive learning strategies and function as ‘mindtools’. These ‘generalisable tools that can facilitate cognitive processing’ (Jonassen, 1992, p.2) make it easier for the learner to process information. In this study four support frameworks were used to assist with the development of problem-solving strategies. The frameworks may be regarded as internal ‘mindtools’ that enhance knowledge construction. During the process of knowledge construction learners may utilise critical thinking skills to evaluate, analyse and correct concepts; creative thinking skills to elaborate, synthesis and visually link concepts and ideas; and complex thinking skills to assess, revise and provide alternative supported arguments (Jonassen, 1996). Using *Exploring the Nardoo* (1995) as the investigative tool, the current investigation sought to develop a better understanding of how learners identify and develop solutions to problems in computer-based learning environments. This information would then be used to help guide the development of a cognitive tool (or tools) to assist learners with their reasoning and problem solving skills.

Several studies have confirmed the lack of understanding of the problem-solving process that learners undertake in ill-structured contexts (Jonassen, 1996; Land & Hannafin, 1996, Lajoie, 1995). Difficulties experienced by learners stem from two essential areas. First, due to the complexity of the problem, the formation of a suitable mental problem representation is often difficult (Voss & Post, 1988). Second, since ill-structured problems involve a number of constraints, learners often form different mental representations of the same problem (Wiley & Voss, 1999). According to Jonassen and Grabinger (1990) both the representation phase and the actual problem-solving phase can be supported in the development of computer-based learning environments. This study sought to investigate a theory-action model (Land & Hannafin, 1996) by observing how participants initially developed their ideas about a solution to a problem and the actions taken to construct a solution that was supported by evidence.

Reasoning

Reasoning is a broad term that is usually applied to a statement in justification or explanation of a thought or action that has transpired. In its application to problem solving, reasoning may be considered to be the cognitive processes concerned with the drawing of conclusions or inferences that support a particular plan of action undertaken by the learner. For a number of years researchers have conducted studies into formal reasoning skills in domain-specific areas (mathematics, science, language) where problems have been set in a particular context. These problems tend to be well-structured and the reasoning demonstrated by the learner is based on the application of concepts and rules that converge in a probable solution. More recently attention has been directed towards studies involving informal reasoning that takes place in real world situations (Wiley & Voss, 1999; Means & Voss, 1996). Informal reasoning is a process that involves the evaluation of evidence to support a claim or conclusion within a problem-solving context. The process is more directly applicable to situations where the problem is ill-defined and requires the use and evaluation of evidence relevant to the problem (Means & Voss, 1996). The common thread of these studies relates to how the learner is expected to arrive at a decision, justify his/her position based on the evidence available and state possible counter-arguments when presenting a solution.

Keys (1995) obtained evidence, which demonstrated that learners were actively engaged in analysing the meaning of data, observations and text during an investigation based on writing in science. During the course of her study learners used reasoning skills as they generated new ideas, assessed and related their personal knowledge with the new ideas, and transferred their modified ideas to new situations. The reasoning skills identified in this study were: posing questions; evaluating and justifying predictions; evaluating observations; identifying patterns; drawing conclusions; formulating models; inferring; identifying relevant information; comparing and contrasting evidence; and discussing concept meaning.

As the investigative problems used for this current research required the use of similar strategies in achieving a final solution, this study has adopted the reasoning skills identified by Keys (1995) as a framework on which to base the data analysis procedures.

Nickerson (1986) argues that a learner's ability to reason includes the capacity to analyse, evaluate and construct arguments. Effective reasoning requires the ability to develop arguments, assess the validity of the argument in generating and testing hypotheses, judge the credibility of assertions made during the problem solving process, identify possible directions for action, and think through the consequences of choosing a particular direction of action.

Scaffolding

Computer-based learning environments provide enriched learning opportunities by presenting information in a variety of forms usually incorporating high quality visual materials in the form of text, images, sound, graphics and video. A variety of pathways to access the information provides a different perspective on not only the information being presented but also on the interrelationships developed through the different metaphors used. Well-designed computer-based learning environments support effective learning through reducing the cognitive load on the user, thus increasing the opportunity for more effective engagement and learning. In attempting ill-structured problems within such an environment many learners need guidance that can lead them to a satisfactory solution(s). Such guidance may be in the form of cognitive tools such as scaffolds that support and direct learners to manage the learning environment, provide a stimulus for an ongoing action or thought, or further develop the learner's cognitive processes.

Hannafin and colleagues (2001) suggest that scaffolding is a process where learners are supported while engaged in a learning or performance task. Traditionally teachers have scaffolded learners to develop enhanced cognitive structures that assist them to solve problems. By building on the learner's experiences, providing challenging authentic activities requiring reflective thinking and working in collaborative groups, teachers can provide the scaffolding needed to bridge the 'zone of proximal development' (Vygotsky, 1978). Scaffolding is generally regarded as support for learners while they are engaged in activities just beyond their capabilities. It ranges from assisting with an entire task to providing occasional support. As the learners' capabilities improve, the teacher gradually reduces the support until the learner becomes self-sufficient with the assigned problem.

Depending on the degree and type of scaffolding offered within computer-based learning environments, the learner may use the support system to assist with the planning process or as part of their ongoing development of higher-order thinking skills. Guzdial (1993) suggests the goal of scaffolding is twofold. Initially scaffolding enables learners to achieve a level of success that would not be possible without the support. Secondly, as the learner's ability level increases the level of scaffolding decreases until learning is facilitated without the supporting framework. For different problem-solving scenarios the type and level of scaffold available should vary to cater for not only the different activities but also for the variation in the learner's knowledge.

In an attempt to support the structural knowledge (Beissner et al, 1993; Diekhoff, 1983) of each participant during the problem-solving process four specific support frameworks were identified for use in this study. Each of these support frameworks, Concept Mapping (Novak, 1990), Venn Diagrams (Gunstone & White, 1986), Critical Thinking (Ennis, 1991) and Six Thinking Hats (De Bono, 1992) have been identified as alternative learning strategies that assist learners in processing and analysing information. It was thought that the support framework would provide cognitive support for problem solving and the development of higher-order thinking skills that would facilitate more efficient problem clarification, together with better reasoning and argumentation outcomes.

Method

This exploratory study (Yin, 1994) focussed on the strategies used by participants as they investigated two problems set within a constructivist learning environment. The study's objective was to gain a clearer understanding of how learners search for and identify supporting information, form or clarify conceptual links, and organise information to support their argument. The role of the qualitative researcher as the main research instrument in observing and interacting with participants, as well as collecting and analysing data, contrasts with the objectivity and impartiality valued in the quantitative approach. This feature of qualitative research raises issues of subjectivity in data collection and interpretation in that the evidence collected and the conclusions drawn come from a single perspective. Peshkin (1988) argues that all researchers should systematically identify the ways in which their subjectivity shapes their inquiry and its outcomes. In the current setting the researcher's ability to interpret experiences within the environment is of central importance in the focus of the study. For this study it is argued that the researcher is a legitimate member of the group setting, being a member of the original design team for the software and a science teacher with twenty years experience as a classroom practitioner. To support the reliability of the data an outside reader – an experienced science teacher with a Masters degree in Environmental Education – was approached to review the criteria used in assessing participants' responses. The researcher and reader discussed the categories suggested in reviewing one example from each of the four frameworks. The reader independently reviewed one further example from each framework for comparison with the researcher's evaluation before finalising the criteria used in the study.

Setting and Participants

The study was carried out over a period of twelve weeks and involved a sample of thirty-two undergraduates (27 female, 5 male) from the University of Wollongong. The participants, all volunteers, were drawn from an introductory Information Technology class that is a core subject for both the Bachelor of Education and Bachelor of Teaching courses offered by the Faculty of Education. The female/male ratio of the participants in this study is a reflection of the student enrolment in these courses. The age of the participants ranged from twenty to forty-five years.

Once the rationale for the study had been explained to the participants they were assigned to one of four tutorial groups for training in both their allocated support framework and use of the CD-ROM. For the problem-solving phase of the study the participants were then asked to work individually on the specific problems chosen for the research.

Procedures

Prior to data collection a protocol was developed to examine and record the interactions of participants through their problem-solving approaches. The criteria included in the protocol were based on reviews of related studies (Fernandes & Simon, 1999; Stratford, Krajcik, & Soloway, 1998; Land & Hannafin, 1997; Keys, 1995).

The first stage of the research, the training phase, involved tutoring all participants in their designated support framework. This was followed with a further tutorial session with the operation of the CD-ROM, *Exploring the Nardoo*, where the specific support framework was applied in researching alternative problems to those used in the study. The second stage, the problem-solving phase, involved the researcher as a participant observer with each member of the study group. Each participant was allocated the same problem(s) to solve and asked to investigate the problem(s) using the support of the paper-based support framework. Minimum guidance from the researcher was provided during this phase.

During the problem-solving process, observational field notes were taken on learner activity and resource interaction. Notes were recorded in an observations booklet designed by the researcher. This booklet contained a series of visual indicators (iconic representations) to each of the embedded media elements that related to the problem under investigation. This allowed the researcher to accurately record a chronological sequence of events during the individual problem-solving approaches. To verify observations, the assistance of a colleague was sought and observational notes taken by the researcher were compared with her observations.

Participant artefacts, transcriptions of audio-recorded think-aloud comments of participants, researcher observations and a post-experience questionnaire were the primary sources of data collection. Participant artefacts comprised notes collected in a computer-based notebook, (the PDA, a tool within the software environment), and handwritten workbook notes. Notes in the PDA consisted of extracts that had been highlighted and copied from the various media articles, typed notes reflecting development of ideas and measurements related to the problem under investigation. These were analysed using a protocol adapted from a review of related studies (Fernandes & Simon, 1999; Stratford, Krajcik, & Soloway, 1998; Keys, 1995). In collecting think-aloud data, participants were asked to recount the methods they employed in ‘solving’ the problem.

Data analysis & Reliability

Initial interpretation of the data was based on a constant comparative method of analysis (Glaser & Strauss, 1967) in an effort to identify common categories that could be used in the dissection of the participants' cognitive strategies used in problem solving. Cognitive strategies are demonstrated through the learner comprehending information, organising ideas, analysing and synthesising data, choosing between alternatives and evaluating ideas or actions. The demonstrated cognitive strategies that were chosen for the initial analysis in this study were:

- clarification - initial planning & defining problem. Regular referral to problem outline and task. Participant translates, comprehends or interprets information.
- application - researching & gathering of evidence. Participant selects, transfers and uses data to address the problem.
- analysis - highlight evidence to support problem resolution; compare and contrast information; makes inferences. Participant classifies and relates evidence, statements or assumptions.
- synthesis - planning through linking of or between evidence. Participant integrates and combines ideas into a plan or development of a strategy.
- evaluation - informal reasoning to support argument. Participant appraises, assesses and judges on the basis of personal criteria.

Participants’ written work, audiotape recordings and think-aloud transcripts were coded and analysed to identify any emerging patterns with each of the four support frameworks and the individual informal reasoning skills used by each participant. To verify the trustworthiness of the participants’ action plans throughout both the problem-solving investigations a process of member checking (Stake, 1995) was undertaken. One participant from each of the four targeted groups was asked to listen to his/her individual audiotape recordings and review the researcher's interpretation of the data collected pertaining to his/her individual problem-solving strategies. Each of these participants had completed both assigned problems. In each case the researcher's interpretation was based on data collected from the audio transcripts, the participant's notes in the PDA and/or workbook, and the researcher's observational notes. The purpose of the member checking procedure was to ensure the accuracy of the findings generated by the researcher. On completion of the review of the researcher's interpretation each of the four participants provided a written acknowledgment of this process confirming the accuracy of the original analysis.

Results

Critical Thinking Support Framework

In reviewing the strategies used by participants in this group several generalisations can be made. When clarifying the problem only two participants engaged in in-depth analysis of what was required of the problem context and task. This was achieved through careful highlighting of key phrases in the text, paraphrasing of these ideas, and the recording of these ideas in either the PDA or the workbook. Initial clarification from the remainder of this group was considered to be low quality, being restricted to a single read through of the text with little or no reinforcement.

In terms of problem resolution, most participants engaged in some analysis of the media reports that were accessed. The degree of analysis varied from an initial reading (newspapers), listening (radio) and viewing (television), followed by the recording of a key point or idea that was considered important, through to secondary access of the linked media for more in-depth analysis. During these occasions, sections of text were highlighted and key ideas were paraphrased and recorded for later referral. Throughout the information-gathering process the two participants who had spent additional time in clarification of the problem engaged in quality strategies that included highlighting, paraphrasing, recording key points that linked to their original concepts of the task, made inferences and expressed a degree of causal reasoning between evidence. Three other participants exhibited similar strategies but to a lesser degree. The remainder of the group appeared to have no clear strategy or exhibit any degree of goal setting throughout the problem solving process. These participants exhibited weak reasoning strategies in developing their solutions.

Six Thinking Hats Support Framework

When working towards a solution through investigation of the supporting media elements, most of this group began with a random exploration of the region in which the problem is set. Reports were interpreted from primary access to the media source without secondary referral to the linked media. Brief notes were made in the participant's workbook of points that provided support to the particular line of inquiry and linked to the initial task. All participants engaged in some form of explanation about cause-and-effect relationships from the evidence they had collected. However the quality of these responses was varied. Some participants demonstrated good causal reasoning, recognising relationships between evidence and prioritising the evidence when providing reasons to support a solution. Others developed solutions that were based on generalisations without support from evidence. Little attempt was made to evaluate or prioritise the evidence collected and this reflected the apparent lack of clarification each of these participants had demonstrated at the commencement of each of the tasks.

In researching evidence to support the problem, the majority of participants demonstrated analysis skills that included highlighting sections of text that were considered important, noting key words or phrases in the workbook and paraphrasing the main ideas associated with the media report that had been reviewed. When developing a solution to the problem the quality of responses was again varied with some participants demonstrating better causal reasoning based on relationships between evidence in establishing cause and effect. The remainder of this group proposed solutions based on generalisations without the support of evidence.

Venn Diagram Support Framework

In working through a series of steps to resolve the problem these participants appeared to have some common strategies in their approach to the task. Even though the search strategies varied from random access to a more structured approach in locating evidence, the analysis of each article exhibited some common characteristics. Participants regularly highlighted key points from within the articles, paraphrasing the main ideas, and recording them for later referral. Throughout this process many participants linked information between articles in suggesting possible causes for the problem. A common feature of their interpretation of the evidence to reach a solution was the inability of group members to specifically identify causes for the problem under investigation.

Of this group only two participants identified the main cause(s) of the problem and the possible ways to control them. The remainder of the group indicated the main cause of the problem but did not suggest ways to overcome it. No supporting evidence was used to reinforce their reasoning, possibly because several participants had missed locating related media reports that may have provided this guidance. Little attempt was made to reflect on the information, to identify patterns or common attributes, or to explain predictions based on evidence collected. In these cases little evidence of strategy use was evident and individual participants appeared to used alternative pre-existing strategies.

Concept Mapping Support Framework

In working through a series of steps to resolve the problem(s) a range of cognitive approaches were used. The degree of analysis for most participants included an initial reading (newspapers), listening (radio) and viewing/listening (television) of the related media elements, followed by the recording of the main points of the article in either the PDA or workbook. Some participants paraphrased sections of articles that had been accessed, expressing opinions or making inferences about the issues that had been encountered. In developing a solution most participants did not support their argument with evidence that they had collected, but instead based their reasoning on generalisations. Two participants appeared to have clearer strategies, using reasoning skills based on some prioritising of the evidence that they had located and analysed to support the solution to the problem.

Participants approached the use of this framework with varying degrees of success. Some participants identified key concepts from the problem context and task outline and recorded these as headings in their workbook. As evidence was located and analysed key points were added to their ‘map’ of the problem space but for most no hierarchical order was established. Instead the key points were added in a chronological listing reflecting the order of access from their individual search patterns. Most ‘maps’ illustrated a flow of ideas, sometimes linked with arrows, that represented an individual collection of ideas associated with a personal approach to solving the problem.

Discussion & Conclusion

Two inquiry-based problems of an ill-structured variety were used in the study and presented in a virtual setting through the CD-ROM, *Exploring the Nardoo*. Such computer-based learning environments provide a useful means of engaging learners in scientific inquiry allowing opportunities for learners to engage in problem solving experiences that are difficult to create in classroom situations. Participants were provided with, and instructed in, the use of one of four support frameworks to assist them in their investigation of the problem(s).

Participants used a variety of strategies in their approach to problem solving. Some participants were able to articulate the problem space and identify different opinions and perspectives on the problem. Others appeared to have few clear goals or objectives in their strategies. In general terms, it appeared that those participants with limited subject knowledge engaged in more primitive search strategies. When attempting to develop a possible solution(s), and assess the viability of the evidence to support their argument, a majority of participants failed to focus their solution on the precise aspects of the problem. For these participants it appeared as though they had not clearly identified the purpose of the investigation from the initial reading of the problem.

In the use of the designated support framework there were substantial differences in the approaches taken by participants. The frameworks were provided, to assist participants, as thinking tools that could be used to help them judge and assess the credibility of potentially conflicting information and to develop strategies to resolve these conflicts, to clarify issues, to think strategically and critically, and to make judgements and decisions. Based on the data collected the following generalisations are made:

- both the Six Hats and the Critical Thinking frameworks provided stimulus for participants to seek out information;
- the Venn Diagram and Concept Mapping frameworks focussed more on the organization of ideas once they had been identified.

Participants using the first two frameworks presented clearer representations and better argued their problem solutions. One reason for the apparent success of these two frameworks may be that they are scaffolding mechanisms that activate specific cognitive processes in the learner.

This exploratory investigation of learner support frameworks raises more questions than it answers, but it does indicate that learners engaged in interactive computer-based learning need support to represent the knowledge and information they have acquired in the process. This could be achieved through the development of additional cognitive tools to support the process through helping learners identify patterns, links and similarities in these complex information environments. This study indicates that:

- learners are assisted in the problem-solving process through the posing of questions that help generate ideas;
- questions that are generated need to be specific to the context of the problem domain;
- when theories or ideas are generated, learners need support in testing and ranking such theories based on their relative merit in supporting the problem solution.

The development of cognitive tools to further support novice learners from a variety of backgrounds is needed to help them process information more effectively in computer-based learning environments. These tools would help learners to identify patterns, links and similarities in complex information environments encouraging the development of more effective reasoning skills. Such tools need to be developed and designed so that they assist novices in developing more specific strategies that lead to appropriate solutions. Further research involving a variety of learning environments may demonstrate a broader scope for the development of a scaffolding system for different types of learners in different domains. This may provide a clearer indication of what types of learners could be advantaged, and in what learning environments, by using technology-based support structures.

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